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GRAPHICAL ANALYSIS OF THE SENSITIVITIES  
OF ATCAL IN THE FORCEM MODEL

by

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June 1989

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OF ATCAL IN THE FORCEM MODEL

by

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Submitted in partial fulfillment of the  
requirements for the degree of

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## ABSTRACT

This is an analysis of an attrition process in the context of its theater model. A graphical data analysis of the sensitivities of ATCAL with respect to FORCEM operational data was performed. Given the ATCAL results from various FORCEM runs, the sensitivity of ATCAL within the FORCEM model to the effects of frontage of engagement and presence of important weapon systems was investigated.

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## I. INTRODUCTION

### A. INTRODUCTION

Verification and validation of computer simulations of large complex systems such as theater level combat operations is difficult at best. In practice, this is not a single event, but continues to occur throughout the life of the models involved. While the basic intent is to insure that the model is true to its design and that the design reasonably approximates reality, the effort also yields insight into model sensitivity and possible utility of information generated by the model.

The purpose of this project is to analyze an attrition process in the context of its theater model. This study will examine sensitivity with respect to certain variables, to verify that the process, in this context, provides an intuitively appealing output, and to look for items which may be used as simple performance predictors in other aspects of the model. The process under investigation is the Attrition Calibration (ATCAL) process, used by the Army Concepts Analysis Agency (CAA) as the attrition mechanism in its theater-level models, Concepts Evaluation Model (CEM) and Force Evaluation Model (FORCEM).

## B. BACKGROUND

CEM is a deterministic theater model of ground and air combat which has been developed through several versions since about 1970. [Ref. 1:pp. 1-11]

FORCEM is a more detailed computer simulation model portraying combat, combat support, and combat service support in a theater of operations. It is a fully-automated, deterministic, and time-stepped model, with a module for each major functional area being activated once each twelve-hour time cycle. It was developed by CAA during the period 1982-1984, and is now operational. Applications are in studies that determine the capabilities of current combat forces; requirements for support forces; and requirements for personnel, supplies, and major items of equipment. [Ref. 2:p. 2]

ATCAL is an Attrition Calibration Model which was developed in the early 1980's by CAA for use in the CEM and FORCEM theater level simulations. ATCAL consists of a number of non-linear equations which can be used to compute weapon systems attrition of opposing forces (if values for several input parameters are known). The same equations can be used "backwards" to determine values for the parameters from the output of a higher resolution model such as CAA's divisional Combat Sample Generator (COSAGE). The ATCAL process contains both an attrition model and a consistent calibration procedure.

The ATCAL model does not step through time, but rather reflects the casualty rates of the division level engagement to which it is calibrated. [Ref. 3:p. 6-1]

Operational use of FORCEM in 1987 and early 1988 generated a backlog of corrections, enhancements, and new developments which were desired in the model. In May 1988, a task force was constituted within CAA to address these needs in a two-phased program. As part of phase one, an analysis was conducted to determine how certain aspects of the model, including the mechanics of forming combat engagements and certain computer-science related issues, affected the attrition process.

Other tests have also been conducted at CAA which examined sensitivities of various aspects of the COSAGE-ATCAL-FORCEM integrated system of models. These controlled tests have generally shown ATCAL to be robust, but have pointed out some areas of interest for further testing. These areas and the areas of interest found through the task force phase one analysis form the base from which this study is derived. The specific focus of this study is to examine some of the sensitivities of ATCAL in its operational setting. [Ref. 4]

ATCAL itself is sensitive to rate of fire and engagement frontage [Ref. 3:pp. 6-11]. The actual effect of these sensitivities has never been analyzed in FORCEM operational data. It is appropriate to analyze model results with respect to these sensitivities to verify that the results are sensible

in the simulation. Where these parameters can be adequately controlled, they may also provide mechanisms through which other desired effects can be infused into the FORCEM Model [Ref. 5:p. 1].

#### C. PURPOSE OF RESEARCH EFFORT

The purpose of this study is to perform a graphical data analysis of the sensitivities of ATCAL with respect to FORCEM operational data. Given a history of ATCAL results from various FORCEM runs, appropriate graphical techniques will be applied to illustrate the sensitivity of ATCAL within the FORCEM Model to the effects of frontage of engagement and presence of important weapon systems.

This is important in light of the previous tests done on sensitivities of the COSAGE-ATCAL-FORCEM integrated system of models. Graphical analysis will provide the first step in the effort to understand the sensitivity of ATCAL within the FORCEM model.



## II. DATA AND METHODOLOGY

### A. DATA

The data used in this analysis is drawn from 20 day combat simulations between a Blue defending force and a Red attacking force. This FORCEM basic data will be referred to as FB. A comparative run was also made using a version of FORCEM which restricted the number of engagements each unit could be involved in per time period so that the number of extremely small engagements was reduced. This set of data of FORCEM restricted engagements will be referred to as FR.

A third set of data was developed by incorporating the version of ATCAL found in CEM into the FORCEM model. This was done to examine the effect in FORCEM of certain processing differences found in the CEM ATCAL. This data set will be referred to as FC.

The characteristics of each of the data sets can be seen in Tables I and II. The data sets were run through the Statistical Analysis System (SAS) using the procedure Univariate to get the results for Table I. The complete output for each of the data sets is in Appendix A.

TABLE I  
DATA SETS

FB - FORCEM BASIC DATA FR - FORCEM RESTRICTED ENGAGEMENTS DATA FC - FORCEM DATA USING CEM's VERSION OF ATCAL		
DATA SET	NUMBER OF OBSERVATIONS	NUMBER OF VARIABLES
FB	47487	18
FR	19985	17
FC	652*	15

\* ENGAGEMENT-LEVEL TOTALS ONLY

TABLE II  
VARIABLES

TIME	Day or night engagement
BRD	Posture of the blue forces ( i.e., defend, delay)
BLUE	Blue unit involved in the engagement
FBLUE	Fraction of the blue unit involved in the engagement (i.e., .33, .5)
RED	Red unit involved in the engagement
FRED	Fraction of the red unit involved in the engagement (i.e., .65, .10)
FRONT	How large a front size the engagement takes place on
AST	A number which represents the different assets of both the red and blue units (i.e., 5-tank for blue, 53-tank for red)
OHAND	The number of a particular asset which is available at the beginning of the engagement.
HITS	The number of that particular asset which were hit during the engagement
KKILL	The number of that particular asset which were killed during the engagement
GLOBE	The system value which is assigned that particular asset
TOASCW	The total combat worth of that asset (number of assets on-hand at the beginning of the engagement times their system value)

TABLE II (CONT)

LOASCW	The lost combat worth of that asset at the end of the engagement (the number of assets hit or killed times their system value)
TOBLCW	The total blue combat worth (all the blue assets time their system value sum together at the beginning of the engagement)
LOBLCW	The number of blue assets lost during the engagement times their system value.
INITRA	Initial force ratio (red's total combat worth/blue's total combat worth at the beginning of the engagement)
FINARA	Final force ratio (red's total combat worth at the end of the engagement/blue's total combat worth at the end of the engagement)
BTNKO	Number of red tanks on-hand at the beginning of the engagement
RTNKH	Number of red tanks hit during the engagement
RTNKK	Number of red tanks killed during the engagement
BTNKO	Number of blue tanks on-hand at the beginning of the engagement
BTNKH	Number of blue tanks hit during the engagement
BTNKK	Number of blue tanks killed during the engagement

## B. METHODOLOGY

Exploratory data analysis techniques are to be utilized to analyze the data described above. The data will be manipulated first using SAS. Subsets of each of the data sets will be put into the GRAFSTAT Package to take advantage of the exploratory data analysis techniques which are available within this package.

Using the techniques provided by both SAS and GRAFSTAT this study will attempt to answer the following questions:

- What effects do frontage changes have on the response of ATCAL in FORCEM?
- Is an increase in final force ratio associated with an increase in frontage?

- How does the presence or absence of important weapon systems in an engagement change the performance of ATCAL in FORCEM results?
- Is there a noticeable change in results when a weapon is absent from an ATCAL engagement?

In reality, an increase in the frontage size might be expected to show an increase in the final force ratio if everything else in the engagement is held constant. We will investigate the response of ATCAL to changing frontage in this study. Similarly, if a weapon system is really important to a unit the absence of this system should cause noticeable changes in the results of the engagements. The killing potential of the unit should be less, so then there are fewer enemy assets being killed. We will attempt to determine if the results from ATCAL confirm this.

There will also be an attempt to identify questions which cannot be answered within the scope of this study or the data provided for future studies.

### III. ANALYSIS OF FRONTAGE EFFECTS

Frontage is the width of the area that a defending unit must control. In the military sense, a unit can control the area by physically being there, or by having the ability to observe the area and deliver effective fire onto it.

Given a fixed size for a defending unit (i.e., a fixed combat worth), it would seem that, as the unit is assigned a larger frontage to defend, its ability to accomplish the mission would decrease as the size of the front increased. Alternatively, a fixed size unit attacking on decreasing frontages might expect increased losses as its maneuver room is reduced. Frontage changes would naturally be a part of any combat model which has attacking and defending forces.

In FORCEM, the frontage associated with a specific engagement is calculated as follows: Engagement Frontage =  $1/2$  [Fraction of Red Division in that Engagement \* Red Division Frontage + Fraction of Blue Division in that Engagement \* Blue Division Frontage]. The division frontages are computed from corps frontages as  $1/N$  \* [Corps Frontage] where N is the number of divisions in the corps. Corps frontage is determined from the corps boundaries which are input by the model operator and intended to represent realistic frontages for the units and operations involved.

Units are apportioned for combat against enemy units by a process based on range. [Ref. 2:pp. 6-11]

The data sets from both versions of ATCAL were investigated to see if changes in frontage size had any effect on the final force ratio. Final force ratio is the ratio of the number of operational red weapon systems times their system values, divided by the number of operational blue weapon systems times their system values at the end of the engagement.

An example of how final force ratio is computed: At end of an engagement all the operational red weapon systems are counted, (5 Tanks, 6 BMPs, 4 Helicopters), the number of operational systems is then multiplied by the system value for that system (Tank = 1.0, BMP = .4, Helicopter = .7) and all of these numbers are added together to get the combat worth of the red unit which is also the numerator of the final force ratio. The system value of a system is input by the model operator. The same procedure is done for the blue units and this total combat worth is used as the denominator of the ratio. [Ref. 2]

It is important to take into account the initial force ratio when examining the relationship between frontage and final force ratio since this will also have an effect on final force ratio. The initial force ratio (that is the ratio of the number of red weapon systems times their system values, divided by the number of blue weapon systems times their

system values at the beginning of the engagement), final force ratio, and frontage size were the three variables in the data sets which were investigated.

To investigate the possibility that changes in the frontage size have no effect on the final force ratio a subset of each of the data sets were made. The subset contained all the engagements where the forces were in the most intense conflict during the day.

Figure 1 depicts a graph of the subset for data set FC. It shows the final force ratio grows rather slowly with the initial force ratio for any fixed range of frontage sizes. This is not what is expected to happen, there should be a tendency for the final force ratio to increase as the frontage size increases. Figure 2 displays two graphs. The top graph shows the empirical density of the initial force ratios vs. the different frontage sizes and the lower graph shows the empirical density of the final force ratios vs. the different frontage sizes. In comparing the two graphs it is apparent at all the frontage sizes that the final force ratios have longer tails toward the higher ratios than do the initial force ratios. The largest changes take place between a frontage size of 5500 meters and 6500 meters. Figure 2 does show that there is some change between final and initial force ratio at all frontage sizes. Although the greatest change takes place where the frontage sizes goes from 5500 meters to 6500 meters, this is not what is expected, the largest changes

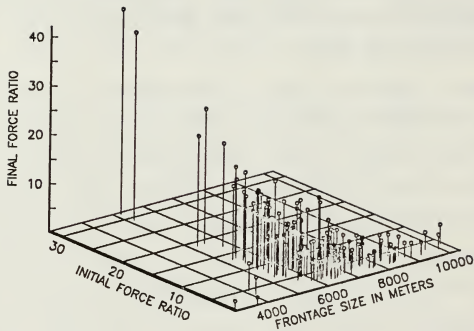


Figure 1. Final Force Ratio Plotted as a Function of Initial Force Ratio and Frontage Size (N=143), Data=FC



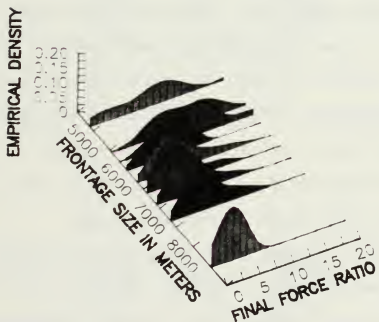


Figure 2. Empirical Densities of Initial and Final Force Ratios Conditioned on Frontage Size (N=143) (Data=FC)

should be seen at the higher frontage sizes. Thus, increases in frontage size do not have a large effect on the final force ratio.

Figure 3 depicts the final force ratio plotted against the initial force ratio conditioned on the frontage size changes. For every point that lies above the line  $y=x$ , blue is losing his combat worth at a greater rate than red considering the initial force ratio and the frontage size. Below the line, red is losing at a greater rate. Thus, there is a tendency at the nominal Cosage 3:1 ratio (this is the ratio at which it would be favorable for a unit to attack and win the engagement), red is consistently losing a higher combat worth proportion relative to blue over all different frontage sizes. It is not until the initial force ratio is larger than 4:1 that the blue force consistently loses a higher combat worth proportion relative to red. It would seem appropriate that at high initial force ratios we should expect to see decisive outcomes, but this is not shown true in Figure 3. The growth of the final force ratio as the initial force ratio increases is relatively slow across the entire range.

A graph of the subset of FR data set is Figure 4. As with the FC data set it does not appear that there is any change in the final force ratio as the frontage increases from this view. The graph in Figure 5 represents the empirical densities of both the initial force ratio and final force ratio against different frontage sizes. The densities at all



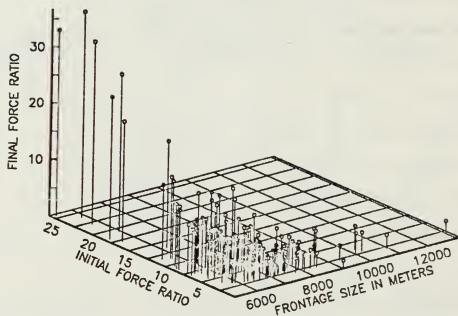


Figure 4. Final Force Ratio Plotted as a Function of Initial Force Ratio and Frontage Size (N=133), Data=FR

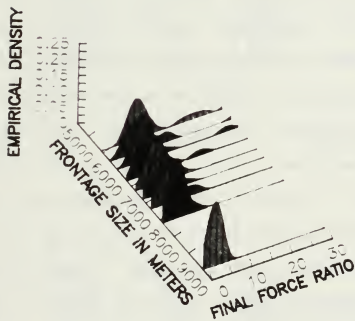
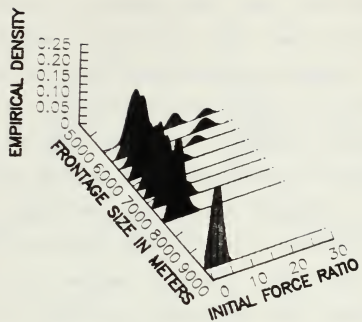


Figure 5. Empirical Densities of Initial and Final Force Ratios Conditioned on Frontage Size (N=133) (Data=FR)

frontage sizes are less peaked in the graph of the final force ratios than in the graph of the initial force ratio. The tails in the final force ratio graph are longer toward the higher frontage sizes than are those in the initial force ratio graph. There is no particular region of frontage sizes where the increase of final force ratio is that much greater than the initial force ratio as shown in Figure 2. There is a change between the distribution of initial and final force ratios at all frontage sizes, but the change between the ratios does not tend to be higher at the high frontage sizes as would be expected. Figure 6 depicts the same graph as Figure 3, except that the subset of FR data set is used in place of the FC data set. Again it is shown that not until the red force has obtained an initial force ratio larger than a 4:1 ratio does the blue force consistently lose a higher combat worth proportion relative to the red force and this is true over the ranges of frontage sizes. There is no evidence of a decisive outcome at high initial force ratios.

The subset of FB data set is depicted in Figure 7. In this figure there appears to be an increase in the final force ratio as the frontage size increases. There also tend to be many more engagements taking place at smaller frontage sizes than were present in the other two data sets. This occurred because command and control rules in FORCEM allowed a unit to engage all enemy units in range. These rules were changed because it was believed so many small engagements are not

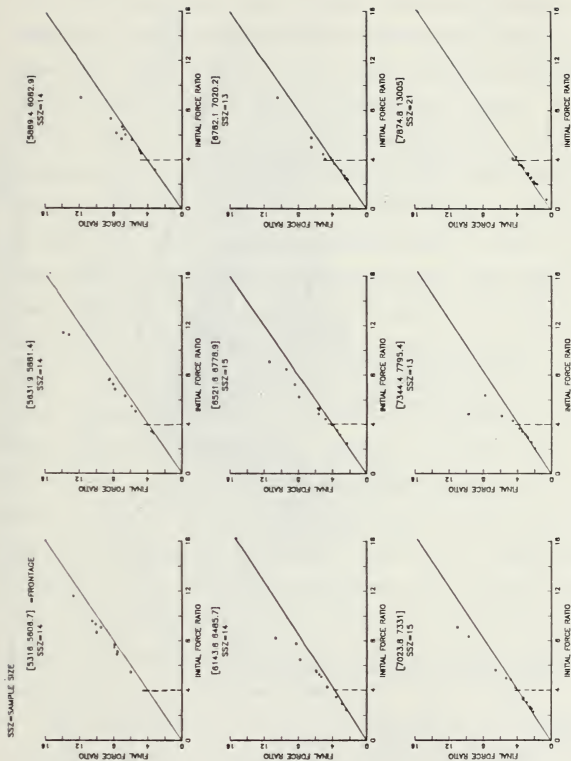


Figure 6. Conditional Scatter-plot of Final vs. Initial Force Ratios Conditioned on Frontage (Data=FR)

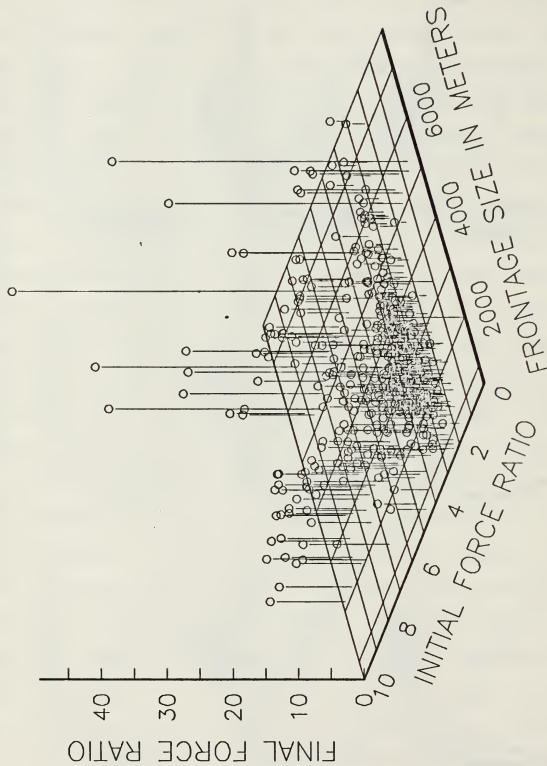


Figure 7. Final Force Ratio Plotted as a Function of Initial Force Ratio and Frontage Size (N=408), Data=FB



desirable in a theater level model. The graphs in Figure 8 display the empirical densities of both the initial force ratio and final force ratio against different frontage sizes. There is a noticeable difference between the density of the final force ratio and the initial force ratio with respect to the thickness of their tails at the higher ratios. A lower overall range of initial force ratios leads to a noticeable migration to lower final force ratios. The range of initial and final force ratios is lower than the range for the FR and FC data. The mode of distributions occurs at lower initial force ratios and is higher compared to the other data sets. Also, there is more spreading of the data in the final force ratio. Figure 9 indicates the same graph as seen in Figure 3 and 6 except with the subset of FB data set. As with the other graphs, the blue force does not consistently lose a higher combat worth proportion relative to the red force until the initial force ratio is higher than a 4 to 1. In fact, where the frontage size is between 2400 and 7650 meters the red force needs at least a 5 to 1 ratio to win consistently. Although in this figure it can be seen that narrow frontage does not point to high initial and final force ratio, it also points to many small engagements which is not considered desirable in a theater level model.

More specifically, in the investigation of changes of frontage size and how they affect the final force ratio in the FORCEM, the following information has been revealed:

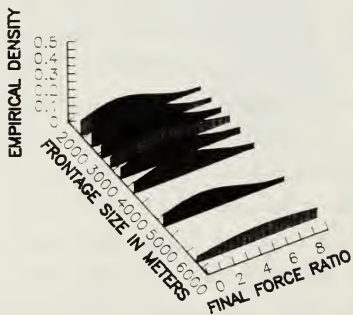
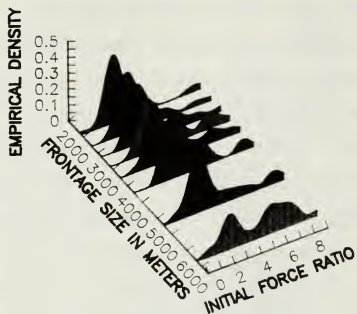


Figure 8. Empirical Densities of Initial and Final Force Ratios Conditioned on Frontage Size (N=408) (Data=FB)

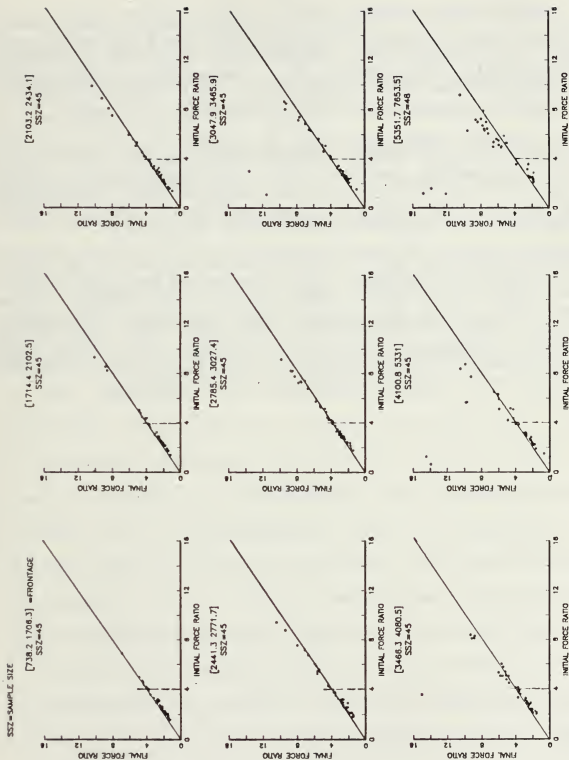


Figure 9. Conditioned Scatter-plots of Final vs. Initial Force Ratios Conditioned on Frontage (Data=FB)

- Changing of frontage sizes show no significant affect in the final force ratio. There is a slight tendency for the final force ratio to increase at all frontage sizes, but the increase is not significant at the larger frontage sizes as would be expected. Thus, frontage changes have no significant affect on final force ratio.
- In order for the red force to consistently lose a lower combat worth proportion relative to the blue force over all the frontage sizes, the red force must have an initial force ratio higher than 4 to 1. Decisive outcomes do not take place when the attacker has a 10:1 ratio and this is definitely opposite to what is expected in a model.
- The combat mechanism used in generating data set FB produces a large number of small frontage, low force ratio (and, therefore, small combat worth) engagements, which are far from the division vs. brigade type engagements which are desired in a theater level model. They dissipate the attackers force unrealistically.
- Between the data set FB and the data sets FC and FR there is a different response: In FB there are many low initial and final force ratios data points at all ranges, where as in FC and FR the initial and final force ratios data points change distribution with range. Also there are larger engagements in the FC and FR data sets. These last two observations are positive results for the model in that they are consistent with what is expected.

#### IV. ABSENCE OF A MAJOR WEAPON SYSTEM

A major weapon system is any weapon system which, when removed from a unit, will degrade the ability of that unit to accomplish its mission. The major weapon system which will be investigated in this thesis is the main battle tank. The main battle tank is the backbone of the heavy combat divisions deployed throughout the world. The question which will be investigated is: How does the absence of an important weapon system affect the performance of ATCAL in FORCEM results?

A subset of the FR data set which comprises all engagements where the forces were in the most intense conflict during the day was used to analyze the question.

The analysis was undertaken using two different approaches. In the first, a single set of data was analyzed to investigate the effect of removing an entire system type. However, problems were encountered with this portion of the analysis, so it was abandoned in favor of an approach which used two subsets of data with different force mixes to address the question. For the sake of completeness, the first method is described briefly before describing the second method.

In the first method, the final force ratios (red/blue) were calculated for a number of different engagements from the FORCEM results with all the weapons systems present. Then the

main battle tank was removed from the blue units and the final force ratios were recalculated.

The final force ratio without the main battle tank minus the final force ratio with the main battle tank was calculated for all the engagements. This difference was then plotted against the fraction of the force made up by the main battle tank. The logarithms of the force ratio differences were plotted to reduce the crowding of the points [Ref. 6:p. 178].

A linear regression of the log of the differences vs. the fraction of the force made up by the main battle tank was performed and the fitted line was drawn on the graph, using the least square and the scatter plot functions of GRAFSTAT. This was done to check if there existed an association between the log of the differences of the final force ratios and the fraction of the force made up by the main battle tank. The graph in Figure 10 displays the scatter plot with the fitted line. There does appear to be an increase in the difference of the final force ratios as the fraction of the force made up by the main battle tank increases. This increase cannot be proven statistically significant for at least two reasons: the plot of the residuals was not normal and the values for the correlation coefficient were low. This indicates a lack of confidence in the association seen; and is probably due to the relatively large variance in the predicted variable and possibly due to the lack of a linear relationship.

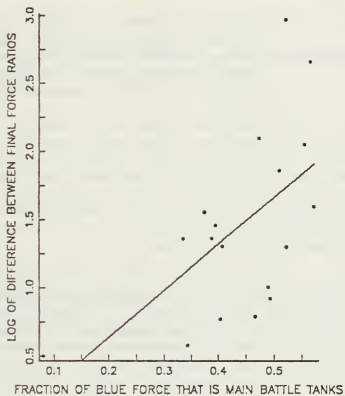


Figure 10. Scatter-plot of the Log of Difference Between Final Force Ratios vs. the Fractions of the Blue Force that is made up of Main Battle Tanks with a Least Squares Fit for the Straight Line (N=18) (Data=Subset of FR)

In order to prove statistically that the absence of an important weapon system affects the performance of ATCAL in FORCEM results a second analytical approach using the Chi-Square test for differences was undertaken [Ref. 7:p. 153]. To perform this test the tank loss fraction of the blue units with a certain main battle tank was calculated and it was also calculated for the blue units without that main battle tank. The tank loss fraction was calculated in the following manner:

$$\text{Tank loss fraction} = \frac{\text{Total combat worth of blue tanks lost}}{\text{Total combat worth of the blue tanks in the engagement}}$$

for both sets of blue units. The tank loss fraction was also calculated for red units with a certain red main battle tank and red units without that red main battle tank. Contingency tables were developed as follows:

TANK LOSS FRACTION OF RED UNITS	BLUE UNITS WITH MAIN BATTLE TANK	BLUE UNITS WITHOUT MAIN BATTLE TANK
0 - .1	f*	f
.1 - $\infty$	f	f

TANK LOSS FRACTION OF BLUE UNITS	BLUE UNITS WITH MAIN BATTLE TANK	BLUE UNITS WITHOUT MAIN BATTLE TANK
0 - .25	f	f
.25 - $\infty$	f	f

\* Actual frequency will be placed in these cells



The first contingency table was used to test if there was a difference between the lethality of blue units with the main battle tank and the blue units without the main battle tanks. The second contingency table was used to test if there was a difference between the vulnerability of the blue units with the main battle tank and the blue units without the main battle tank. Similar contingency tables were used to test the red units to see if any difference existed between the units with the main battle tank and those without the main battle tank. The complete calculations are located in Appendix B for both the blue and red units. The results were that there was no significant difference found between the lethality of the red units with the main battle tank and those without the main battle tank. There was a significant difference between the lethality of the blue units with the main battle tank and the blue units without the main battle tank. There was no significant difference between the vulnerability of the blue units with the main battle tank and the blue units without the main battle tank. No difference was found between the vulnerability of the red units either.

These findings by themselves do not answer the question of whether the absence of a major weapon system affects the performance of ATCAL in FORCEM results, because certain characteristics of the forces or systems themselves may confound these results. For example, the tank absent from the blue force may actually be a more potent killer but have the

same vulnerability as the other tanks in the blue force, or it may be present in a force with some other potent killer which makes it appear more lethal in the red tank loss column. On the red side, the designated tank may be present or absent in numbers too small to affect the overall kill or vulnerability rates.

In order to qualitatively assess whether differences in force composition may be influencing the analysis, the star symbol plots will be used. The star symbol is an interesting way of graphing multivariate data so that you can visually compare the different units. Each star represents one blue unit. There will be two sets, the blue units with the designated main battle tank present and those without the main battle tank. For this study the rays will represent the number of tanks, helicopters (helos), and anti-armor guided missiles (ATGMS) the unit has. The helicopters and anti-armor guided missiles are the two other major tank killing systems in the battlefield within the model. [Ref. 6:pp. 155-159] Figure 11 shows a representative of the star symbol plot and it has each of the rays labeled with the weapon system it represents. This star symbol plot is the legend for the star symbol plots found in Figures 12 and 13.

The force composition may be compared both within and across the data sets using Figures 12 and 13. For instance, the units represented in Figure 12 appear to be reasonably homogeneous with a stable fraction of tanks, but with some

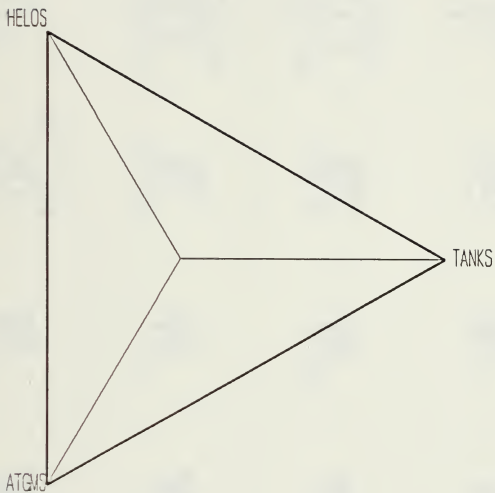


Figure 11. Star Symbol Plot with the Rays Labeled to Represent the Star Symbol Plots in Figures 12 and 13.

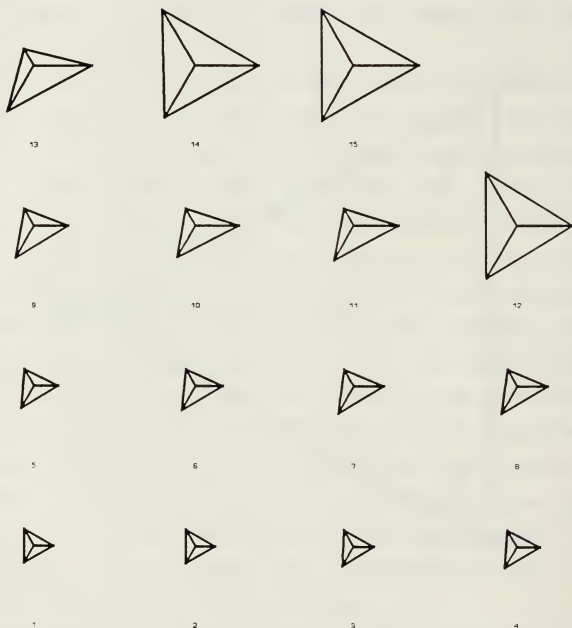


Figure 12. Star Symbol Plot of the Blue Units with the Main Battle Tank

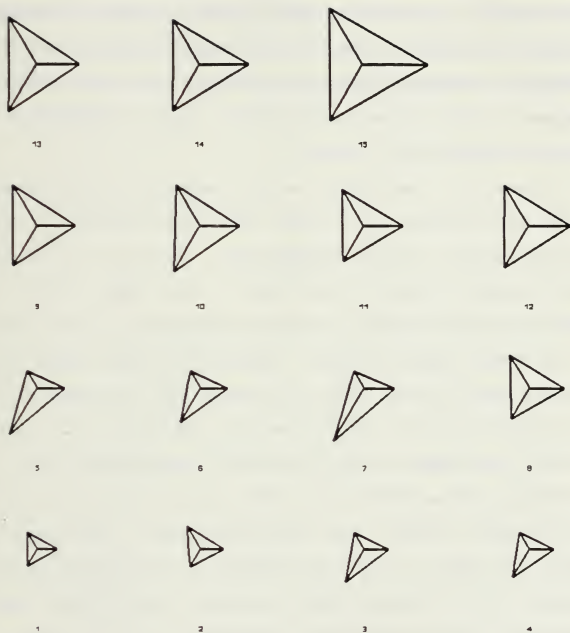


Figure 13. Star Symbol Plot of the Blue Units Without the Main Battle Tank

fluctuation in the fraction of helicopters and ATGMS present. In Figure 13 there appears to be a stable tank fraction present, but more variability in the helicopter and ATGM fractions. Between Figures 12 and 13 these combined differences, while not excessive, may be enough to influence the loss fractions of tanks for the engagements used in this analysis. Because the data provided does not specify precisely which systems killed which, it is not possible to take the analysis any further.

No hard line conclusions can be drawn about the model due to the small sample size of data that was available to test for differences in ATCAL performance. However, the results seem to point to the fact that when a major weapon system is absent some other system or systems compensate for the absence of the major weapon system. This observation needs more definite data to study then is available for this study. From the results of the Chi-Square test for difference only one of the four tests made was able to reject the hypothesis that no difference existed between the units with the main battle tank and the units without the main battle tank. The graph in Figure 10 tends to show an increase in difference as the fraction of the force made up by the main battle tank increases, but no statistical significance can be proven.

The results from the Chi-Square tests for difference show less effect in the data due to the absence of a major weapon system than might be expected, but in light of other factors,

it is hard to attribute this observation to the performance of ATCAL. The small sample size available, differences in the forces involved, and lack of specific killer victim information all influence this analysis and weaken any conclusion with respect to ATCAL performance. However, the techniques employed here would be appropriate in conducting a controlled analysis of this question when more detailed data is available.

## V. CONCLUSIONS

### A. SUMMARY

The purpose of this thesis was to analyze an attrition process in the context of its theater model. A graphical data analysis of the sensitivities of ATCAL with respect to FORCEM operational data was performed. Given the ATCAL results from various FORCEM runs, the sensitivity of ATCAL within the FORCEM model to the effects of frontage of engagement and presence of important weapon systems was investigated. The following observations have been made:

- Changing of frontage size show no significant effect on the final force ratio.
- In order for the red force to consistently lose a lower combat worth proportion relative to the blue force over all the frontage sizes, the red force must have an initial force ratio higher than 4:1. Decisive outcomes do not take place when the attacker has a 10:1 ratio.
- Large numbers of small frontage, low force ratio engagements, which are far from the division versus brigade type engagements which are wanted in a theater level model, dissipate the attacker force.
- Restricting the number of engagements each unit can be involved in per time period so that the number of extremely small engagements are reduced causes the initial and final force ratios data points to change distribution with range. Also there are larger engagements taking place which are positive results for the model.
- Absence of a major weapon system seemed to have only limited effect on the ATCAL results tested, but several factors may have influenced these results. More detail and control is required in the data to be able to draw ATCAL specific conclusions.



## B. POSSIBLE CORRECTIONS

The method which was used in data sets FR and FC so that the unit does not get involved in too many engagements in a time period should be retained in FORCEM so that the number of small engagements will be reduced.

The process for calculating the engagement frontage in FORCEM requires further testing and possible modification so that frontage will have a discernible effect on the outcome of battle.

## C. ADDITIONAL POSSIBLE AREAS OF STUDY

If there is additional interest in the sensitivities of ATCAL with respect to FORCEM, topics remaining open for research are:

- The effect of removing a major weapon system needs to be further studied with more detailed data.
- What effect does the wide variation in size and force mix of engagements have on the performance of ATCAL?
- What important change in response is due to special systems such as close air support?

In order to perform any of the above mentioned areas of research basic knowledge of both the ATCAL and FORCEM model is recommended. Also close coordination with CAA is necessary to provide data with suitable detail to conduct the desired analysis.

## APPENDIX A

## DATA

```

1      FORCEN BASIC DATA (FB)
4      PROC UNIVARIATE DATA = DD1.E6;
5      VAR TIME--FINARA;

```

## UNIVARIATE

VARIABLE=TIME

MOMENTS			
N	47487	SUM WGTs	47487
MEAN	4.87355	SUM	231431
STD DEV	2.9125	VARIANCE	8.48267
SKEWNESS	-0.0711565	KURTOSIS	-1.155
USS	1530697	CSS	403808
CV	59.7823	STD MEAN	0.0133653
T. MEAN=0	364.842	PROB> T	0.0001
SGN RANK	486720813	PROB> S	0.0001
NUM	44123		

QUANTILES (DEF=4)				EXTREMES	
100% MAX	9.5	99%	9.5	LOWEST	HIGHEST
75% Q3	7.5	95%	9	0	9.5
50% MED	5.5	90%	0.5	0	9.5
25% Q1	2.0	10%	0	0	9.5
0% MIN	0	1%	0	0	9.5
RANGE	9.5				
Q3-Q1	0				
MODE	0				

## UNIVARIATE

VARIABLE=BRD

MOMENTS			
N	47487	SUM WGTs	47487
MEAN	12.6844	SUM	602342
STD DEV	5.4131	VARIANCE	29.3017
SKEWNESS	0.105552	KURTOSIS	-1.55705
USS	9031740	CSS	1391420
CV	42.6754	STD MEAN	0.0248404
T. MEAN=0	510.634	PROB> T	0.0001
SGN RANK	563765664	PROB> S	0.0001
NUM	47487		

QUANTILES (DEF=4)				EXTREMES	
100% MAX	20	99%	20	LOWEST	HIGHEST
75% Q3	18	95%	20	6	20
50% MED	10	90%	6	6	20
25% Q1	6	10%	6	6	20
0% MIN	6	1%	6	6	20
RANGE	14				
Q3-Q1	12				
MODE	6				

## UNIVARIATE

VARIABLE=FRONT

MOMENTS			
N	47487	SUM	WGTS
MEAN	328.837	SUM	47487
STD DEV	142.837	VARIANCE	15511794
SKEWNESS	1.01984	KURTOSIS	22061.2
USS	6114676497	CSS	138137
CV	43.4723	STD MEAN	1047694739
T MEAN=0	47487	PROB> T	0.681623
SGN RANK	563765664	PROB> S	0.0001
NUM	47487		

## QUANTILES(DEF=4)

100% MAX	1046.66	99%	756.51
75% Q3	404.08	95%	601.31
50% MED	301.59	90%	543.1
25% Q1	214.59	10%	123.83
0% MIN	48.16	1%	134.83
			95.14
RANGE	998.5		
Q3-Q1	189.79		
MODE	190.48		

## EXTREMES

LOWEST	HIGHEST
48.16	1046.66
48.16	1046.66
48.16	1046.66
48.16	1046.66
48.16	1046.66

## UNIVARIATE

VARIABLE=AST

MOMENTS			
N	47487	SUM	WGTS
MEAN	61.5547	SUM	47487
STD DEV	28.0058	VARIANCE	2923050
SKEWNESS	-0.39991	KURTOSIS	784.324
USS	217171980	CSS	-0.917641
CV	45.4974	STD MEAN	37244393
T MEAN=0	47487	PROB> T	0.128517
SGN RANK	563765664	PROB> S	0.0001
NUM	47487		0.0001

## QUANTILES(DEF=4)

100% MAX	102	99%	102
75% Q3	87	95%	96
50% MED	65	90%	90
25% Q1	40	10%	21
0% MIN	4	1%	5
			4
RANGE	98		
Q3-Q1	47		
MODE	5		

## EXTREMES

LOWEST	HIGHEST
4	102
4	102
4	102
4	102
4	102

## UNIVARIATE

VARIABLE=OHAND

## MOMENTS

N	47487	SUM	WGTS	47487
MEAN	34.6687	SUM		1646311
STD DEV	153.033	VARIANCE		23419.1
SKEWNESS	13.4161	KURTOSIS		257.69
USS	1169154656	CSS	1112079265	
CV	441.473	STD MEAN		0.70376
T: MEAN=0	49.3673	PROB> T		0.0001
SGN RANK	563765664	PROB> S		0.0001
NUM ** 0	47487			

## QUANTILES(DEF=4)

100% MAX	5186	99%	569.733
75% Q3	17.67	90%	108.736
50% MED	7.02	80%	1.48
25% Q1	2.08	70%	1.02
0% MIN	0.03	60%	0.57
		50%	0.21
RANGE	5185.97		
Q3-Q1	14.39		
MODE	4.32		

## EXTREMES

LOWEST	HIGHEST
0.03	43.1
0.03	42.9
0.03	47.4
0.03	51.48
0.03	5186

## UNIVARIATE

VARIABLE=HITS

## MOMENTS

N	47487	SUM	WGTS	47487
MEAN	1.83319	SUM		87052.7
STD DEV	5.74933	VARIANCE		33.0548
SKEWNESS	14.9448	KURTOSIS		1386.03
USS	1729225	CSS	1363841	
CV	313.222	STD MEAN		0.0263834
T: MEAN=0	69.4228	PROB> T		0.0001
SGN RANK	404221078	PROB> S		0.0001
NUM ** 0	40210			

## QUANTILES(DEF=4)

100% MAX	395.06	99%	23.8736
75% Q3	1.29	90%	6.26
50% MED	0.03	80%	4.57
25% Q1	0.03	70%	0
0% MIN	0	60%	0
		50%	0
RANGE	395.06		
Q3-Q1	1.26		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	136.44
0	145.31
0	168.31
0	184.94
0	395.06

# UNIVARIATE

VARIABLE=TOASCW

MOMENTS				
N	47487	SUM	WGT5	47487
MEAN	2.29222	SUM		108851
STD DEV	5.76316	VARIANCE		29.9878
SKEWNESS	1.673512	KURTOSIS		49.4148
USS	238.9	CSS		1424002
CV	91.261	STD MEAN		0.0251296
T MEAN=0	423402641	PROB>T		0.0001
SGN RANK	41153	PROB> S		0.0001
NUM	== 0			

## QUANTILES(DEF=4)

100% MAX	99.41	99%	26.98
75% Q3	1.85	95%	10.97
50% MED	0.51	90%	5.93
25% Q1	0.07	10%	0
0% MIN	0	5%	0
RANGE	99.41	1%	0
Q3-Q1	1.78		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	90.73
0	93.84
0	94.97
0	99.41

# UNIVARIATE

VARIABLE=LOASCW

MOMENTS				
N	47487	SUM	WGT5	47487
MEAN	0.305974	SUM		14529.8
STD DEV	1.3988	VARIANCE		1.95664
SKEWNESS	15.6969	KURTOSIS		423.446
USS	97358.7	CSS		22913
CV	457.162	STD MEAN		0.00641901
T MEAN=0	47.6669	PROB>T		0.0001
SGN RANK	186001363	PROB> S		0.0001
NUM	== 0			

## QUANTILES(DEF=4)

100% MAX	74.68	99%	5.0336
75% Q3	0.51	95%	0.33
50% MED	0.07	90%	0
25% Q1	0	10%	0
0% MIN	0	5%	0
RANGE	74.68	1%	0
Q3-Q1	0.1		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	39.12
0	39.47
0	46.32
0	52.39
0	74.68

## UNIVARIATE

VARIABLE=TOBLCW

MOMENTS			
N	47372	SUM WGTs	47372
MEAN	24.0792	SUM	1140701
STD DEV	26.6573	VARIANCE	710.617
SKEWNESS	2.93868	KURTOSIS	12.5386
USS	61130103	CSS	33662419
CV	110.705	STD MEAN	0.122477
T-MEAN=0	126.605	PROB>T	0.0001
SGN RANK	561038439	PROB> S	0.0001
NUM -= 0	47372		

QUANTILES(DEF=4)			EXTREMES	
100% MAX	275.11	99%	135.172	
75% Q3	28.38	95%	77.92	
50% MED	14.25	90%	54.187	
25% Q1	8.28	10%	4.27	
0% MIN	1.42	5%	2.83	
RANGE	273.69			
Q3-Q1	19.9			
MODE	8.11			

MISSING VALUE  
COUNT 115  
% COUNT/NOBS 0.24

## UNIVARIATE

VARIABLE=LOBLCW

MOMENTS			
N	47372	SUM WGTs	47372
MEAN	2.07773	SUM	984292
STD DEV	3.02657	VARIANCE	9.16014
SKEWNESS	4.40846	KURTOSIS	29.8451
USS	638441	CSS	433925
CV	145.663	STD MEAN	0.0139056
T-MEAN=0	149.443	PROB>T	0.0001
SGN RANK	561038439	PROB> S	0.0001
NUM -= 0	47372		

QUANTILES(DEF=4)			EXTREMES	
100% MAX	35.75	99%	15.44	
75% Q3	2.4	95%	6.98	
50% MED	1.09	90%	4.93	
25% Q1	0.49	10%	0.73	
0% MIN	0.01	5%	0.05	
RANGE	35.74			
Q3-Q1	1.91			
MODE	0.13			

MISSING VALUE  
COUNT 115  
% COUNT/NOBS 0.24

## UNIVARIATE

VARIABLE=INITRA

## MOMENTS

N	47372	SUM WGTS	47372
MEAN	7.74719	SUM	130140
STD DEV	1.84869	VARIANCE	3.35639
SKEWNESS	1.55567	KURTOSIS	2.00127
USS	5.15567	CSS	158048
ICV	66.489	STD MEAN	0.00839223
STON MEAN=0	327.349	PROB> t	0.0001
STON RANK	561038	PROB> s	0.0001
NUM	47372		

## QUANTILES(DEF=4)

100% MAX	9.886	99%	8.85
75% Q3	3.336	95%	6.855
50% MED	4.1	90%	5.399
25% Q1	0.000	10%	0.31
0% MIN	1.0		
RANGE	9.886		
Q3-Q1	1.000		
MODE	1.0		

## EXTREMES

LOWEST	HIGHEST
0.05	9.886
0.05	9.886
0.05	9.886
0.05	9.886

MISSING VALUE  
COUNT 115  
% COUNT/NOBS 0.24

## UNIVARIATE

VARIABLE=FINARA

## MOMENTS

N	47372	SUM WGTS	47372
MEAN	7.7446	SUM	140906
STD DEV	5.21138	VARIANCE	27.1315
SKEWNESS	5.86186	KURTOSIS	57.2359
USS	907657	CSS	488536
ICV	107.965	STD MEAN	0.0147547
STON MEAN=0	201.834	PROB> t	0.0001
STON RANK	561038	PROB> s	0.0001
NUM	47372		

## QUANTILES(DEF=4)

100% MAX	48.71	99%	14.46
75% Q3	3.336	95%	7.97
50% MED	4.1	90%	5.399
25% Q1	0.000	10%	0.31
0% MIN	1.0		
RANGE	48.63		
Q3-Q1	1.000		
MODE	1.0		

## EXTREMES

LOWEST	HIGHEST
0.08	48.71
0.08	48.71
0.08	48.71
0.08	48.71

MISSING VALUE  
COUNT 115  
% COUNT/NOBS 0.24

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22

# FORCEM RESTRICTED ENGAGEMENTS DATA (FR)

```

INPUT  TIME  3-5
      BRD    6-8
      BLUE  10-15
      BLUE  17-21
      RED    22-28
      FRED   30-34
      FRONT  35-42
      AST    44-46
      OHAND  48-56
      HITS   56-62
      GLOBI  66-73
      FOASCW 74-80
      LOASCW 82-87
      TOBLCW 89-94
      LOBLCW 96-101
      INITRA 103-107
      FINARA 109-114;
PROC UNIVARIATE DATA= E32 ;
VAR TIME--FINARA;

```

UNIVARIATE

VARIABLE=TIME

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	4.47245	SUM	89382
STD DEV	2.60391	VARIANCE	6.78035
SKWENESS	0.0827012	KURTOSIS	-0.960139
USS	532255	CSS	135499
CV	58.2255	STD MEAN	0.018493
T: MEAN=0	342311	PROB> T	0.0001
SGN RANK	91934538	PROB> S	0.0001
NUM -= 0	19176		

## QUANTILES(DEF=4)

100% MAX	9.5	99%	9.5
75% Q3	6.5	95%	6.5
50% MED	2.5	90%	2.5
25% Q1	2.0	10%	0.5
0% MIN		1%	0
RANGE	9.5		
Q3-Q1	4		
MODE	5		

## EXTREMES

LOWEST	HIGHEST
0	9.5
0	9.5
0	9.5
0	9.5



# UNIVARIATE

VARIABLE=FBLUE

## MOMENTS

N	19985	SUM	WGTS	19985
MEAN	0.405209	SUM		8112.08
STD DEV	0.294719	VARIANCE		0.0868394
SKWNESS	0.206959	KURTOSIS		-0.284561
USS	5.22856	CSS		72.6073
CV	72.6073	STD MEAN		0.00208476
T-MEAN=0	184.7033	PROB>T		0.0001
SGN RANK	9985053	PROB> S		0.0001
NUM	19985			

## QUANTILES(DEF=4)

100% MAX	1	99%	1
75% Q3	0.54	95%	1
50% MED	0.333	90%	1
25% Q1	0.159	10%	0.093
0% MIN	0.016	5%	0.079
		1%	0.043
RANGE	0.984		
Q3-Q1	0.381		
MODE	1		

## EXTREMES

LOWEST	HIGHEST
0.016	1
0.016	1
0.016	1
0.016	1
0.016	1

# UNIVARIATE

VARIABLE=RED

## MOMENTS

N	19985	SUM	WGTS	19985
MEAN	103341	SUM		206523784
STD DEV	2144.63	VARIANCE		4599433
SKWNESS	0.1443005	KURTOSIS		-1.4538798
USS	2.1355E+14	CSS		9.192E+10
CV	2.1075229	STD MEAN		15.1703
T-MEAN=0	8851908	PROB>T		0.0001
SGN RANK	99851908	PROB> S		0.0001
NUM	19985			

## QUANTILES(DEF=4)

100% MAX	107025	99%	107025
75% Q3	105015	95%	107024
50% MED	102025	90%	107023
25% Q1	101034	10%	107022
0% MIN	101031	5%	101031
		1%	101031
RANGE	5994		
Q3-Q1	3981		
MODE	101033		

## EXTREMES

LOWEST	HIGHEST
101031	107025
101031	107025
101031	107025
101031	107025
101031	107025

VARIABLE=FRED

# UNIVARIATE

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	0.871773	SUM	17421.2
STD DEV	0.2229705	VARIANCE	0.0527643
SKEWNESS	-1.33698	KURTOSIS	0.344504
USS	16240.7	CSS	1034.25
CV	26.351	STD MEAN	0.00162437
T: MEAN=0	538.481	PROB> t	0.0001
SGN RANK	99855053	PROB> s	0.0001
NUM	19985		

## QUANTILES(DEF=4)

100% MAX	1	99%	1
75% Q3	1	95%	1
50% MED	1	90%	1
25% Q1	0.762	10%	0.472
0% MIN	0.095	5%	0.381
		1%	0.254
RANGE	0.905		
Q3-Q1	0.238		
MODE	1		

## EXTREMES

LOWEST	HIGHEST
0.095	1
0.095	1
0.095	1
0.095	1
0.095	1

# UNIVARIATE

VARIABLE=FRONT

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	6860.76	SUM	137112300
STD DEV	1730.42	VARIANCE	2994363
SKEWNESS	0.879289	KURTOSIS	1.15048
USS	1.001E+12	CSS	5.984E+10
CV	25.222	STD MEAN	12.2405
T: MEAN=0	560.495	PROB> t	0.0001
SGN RANK	99855053	PROB> s	0.0001
NUM	19985		

## QUANTILES(DEF=4)

100% MAX	13005	99%	11953.4
75% Q3	7738.3	95%	10191.0
50% MED	6428.6	90%	5254.1
25% Q1	5716.3	10%	4591
0% MIN	2448.1	5%	3172.2
		1%	
RANGE	10536.9		
Q3-Q1	2022.2		
MODE	11635		

## EXTREMES

LOWEST	HIGHEST
2448.1	13005
2448.1	13005
2448.1	13005
2448.1	13005
2448.1	13005

## UNIVARIATE

VARIABLE=HITS

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	3.4619	SUM	69186.1
STD DEV	7.33618	VARIANCE	53.8195
SKEWNESS	4.17319	KURTOSIS	23.8599
USS	13150.8	CSS	107553.0
CV	211.917	STD MEAN	0.0518341
T: MEAN=0	66.7109	PROB> T	0.0001
SGN RANK	78921014	PROB> S	0.0001
NUM	17767		

## QUANTILES(DEF=4)

100% MAX	112.25	99%	36.7542
75% Q3	3.09	95%	17.79
50% MED	0.69	90%	9.784
25% Q1	0.07	10%	0
0% MIN	0	5%	0
RANGE	112.25	1%	
Q3-Q1	3.02		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	80.77
0	81.76
0	85.39
0	85.68
0	112.25

## UNIVARIATE

VARIABLE=GLOBI

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	0.196315	SUM	3923.36
STD DEV	0.277462	VARIANCE	0.076985
SKEWNESS	2.52159	KURTOSIS	7.50073
USS	2308.58	CSS	1538.47
CV	141.335	STD MEAN	0.00196269
T: MEAN=0	100.024	PROB> T	0.0001
SGN RANK	79856564	PROB> S	0.0001
NUM	17872		

## QUANTILES(DEF=4)

100% MAX	1.475	99%	1.475
75% Q3	0.2792	95%	0.7805
50% MED	0.0939	90%	0.5272
25% Q1	0.0092	10%	0
0% MIN	0	5%	0
RANGE	1.475	1%	
Q3-Q1	0.2704		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	1.475
0	1.475
0	1.475
0	1.475
0	1.475

## UNIVARIATE

VARIABLE=TOASCW

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	7.19784	SUM	143829
STD DEV	15.7764	VARIANCE	247.634
SKEWNESS	4.13521	KURTOSIS	22.1199
USS	5984110	CSS	4948709
CV	218.626	STD MEAN	0.111315
T: MEAN=0	64.666	PROB> T	0.0001
SGN RANK	7980255	PROB> S	0.0001
NUM ^= 0	17866		

## QUANTILES(DEF=4)

100% MAX	188	99%	82.8442
75% Q3	5.66	95%	36.951
50% MED	1.46	90%	22.13
25% Q1	0.24	10%	0
0% MIN	0	5%	0
		1%	0
RANGE	188		
Q3-Q1	5.42		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	157.63
0	164
0	164
0	186
0	188

## UNIVARIATE

VARIABLE=LOASCW

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	0.60957	SUM	12182.3
STD DEV	1.96689	VARIANCE	3.86866
SKEWNESS	6.75512	KURTOSIS	64.8071
USS	84737.3	CSS	77311.4
CV	322.669	STD MEAN	0.0139132
T: MEAN=0	43.8172	PROB> T	0.0001
SGN RANK	42481065	PROB> S	0.0001
NUM ^= 0	13035		

## QUANTILES(DEF=4)

100% MAX	40.91	99%	10.37
75% Q3	0.28	95%	3.167
50% MED	0.03	90%	1.46
25% Q1	0	10%	0
0% MIN	0	5%	0
		1%	0
RANGE	40.91		
Q3-Q1	0.28		
MODE	0		

## EXTREMES

LOWEST	HIGHEST
0	28.74
0	30.25
0	34.91
0	35.9
0	40.91

## UNIVARIATE

VARIABLE=TOBLCW

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	74.0713	SUM	1480314
STD DEV	84.1156	VARIANCE	7075.43
SKEWNESS	2.97926	KURTOSIS	10.8913
USS	251044164	CSS	14133447
CV	1.13489	STD MEAN	0.59501
T-MEAN=0	9985053	PROB> T	0.0001
SGN RANK	19985	PROB> S	0.0001
NUM	19985		

## QUANTILES(DEF=4)

100% MAX	565.2	99%	456.04
75% Q3	82.22	95%	232.55
50% MED	47.22	90%	149.9
25% Q1	24.96	10%	14.44
0% MIN	3.07	5%	11.14
		1%	6.33
RANGE	562.13		
Q3-Q1	57.26		
MODE	16.22		

## EXTREMES

LOWEST	HIGHEST
3.07	565.2
3.07	565.2
3.07	565.2
3.07	565.2

## UNIVARIATE

VARIABLE=LOBLCW

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	5.57662	SUM	111449
STD DEV	5.81112	VARIANCE	33.7691
SKEWNESS	1.99941	KURTOSIS	4.47309
USS	1296349	CSS	574842
CV	104.205	STD MEAN	0.0411062
T-MEAN=0	135.664	PROB> T	0.0001
SGN RANK	9985053	PROB> S	0.0001
NUM	19985		

## QUANTILES(DEF=4)

100% MAX	34.62	99%	26.08
75% Q3	7.42	95%	18.58
50% MED	1.38	90%	13.48
25% Q1	1.68	10%	0.98
0% MIN	0.06	5%	0.61
		1%	0.27
RANGE	34.56		
Q3-Q1	5.66		
MODE	1.68		

## EXTREMES

LOWEST	HIGHEST
0.06	34.62
0.06	34.62
0.06	34.62
0.06	34.62

## UNIVARIATE

VARIABLE=INITRA

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	4.37361	SUM	87406.6
STD DEV	4.19726	VARIANCE	17.6197
SKEWNESS	2.41593	KURTOSIS	7.84487
USS	734391	CSS	352108
CV	95.9747	STD MEAN	0.0296924
T: MEAN=0	147.297	PROB> T	0.0001
SGN RANK	9985053	PROB> S	0.0001
NUM	19985		

## QUANTILES(DEF=4)

100% MAX	31.36	99%	22.11
75% Q3	3.58	95%	12.57
50% MED	3.15	90%	9.06
25% Q1	1.57	10%	0.93
0% MIN	0.19	5%	0.63
		1%	0.32
RANGE	31.17		
Q3-Q1	4.01		
MODE	5.46		

## EXTREMES

LOWEST	HIGHEST
0.19	31.36
0.19	31.36
0.19	31.36
0.19	31.36
0.19	31.36

## UNIVARIATE

VARIABLE=FINARA

## MOMENTS

N	19985	SUM WGTs	19985
MEAN	4.86026	SUM	97132.3
STD DEV	2.53951	VARIANCE	29.1071
SKEWNESS	2.89424	KURTOSIS	11.1576
USS	1033765	CSS	581576
CV	111.004	STD MEAN	0.0381634
T: MEAN=0	127.354	PROB> T	0.0001
SGN RANK	9985053	PROB> S	0.0001
NUM	19985		

## QUANTILES(DEF=4)

100% MAX	43.4	99%	31.62
75% Q3	6.01	95%	14.53
50% MED	3.17	90%	10.44
25% Q1	1.54	10%	0.92
0% MIN	0.17	5%	0.59
		1%	0.31
RANGE	43.23		
Q3-Q1	4.47		
MODE	1.34		

## EXTREMES

LOWEST	HIGHEST
0.17	43.4
0.17	43.4
0.17	43.4
0.17	43.4
0.17	43.4

1           FORCEM DATA USING CEM's VERSION OF ATCAL (FC)

```

4      INPUT  TIME  1-.5
5      BRD      4-.8
6      BLUE    11-.15
7      RED     16-.21
8      FRONT   23-.37
9      RTNKKO  33-.52
10     RTNKKH  39-.44
11     RTNKKK  47-.52
12     BTNKKO  55-.59
13     BTNKKH  62-.67
14     BTNKKK  68-.73
15     TOBLCW  88-1.86
16     LOBLCW  88-.92
17     TNITRA  95-1.00
18     FINARA  102-1.06;
19     PROC UNIVARLATE DATA=CEM;
20     VAR TIME--FINARA;

```

UNIVARLATE

VARIABLE=TIME

# MOMENTS

N	9	651	SUM	WGTS	651
MEAN	9	29186	SUM		6049
STD DEV	4	95744	VARIANCE		24
SKEWNESS	-0.029	6628	KURTOSIS		-1
CUS	7	2181	CSS		15
CV	53	5355	STD MEAN		0.19
T: MEAN=0	47	8279	PROB> T		0.0001
SGN RANK	104	491	PROB> S		0.0001
NUM	-=	0			646

# QUANTILES(DEF=4)

100% MAX	17.5	99%	17.5
50% MED	9.5	90%	16
25% Q3	0	10%	2.5
0% MIN	0	5%	1.5
		1%	0.5
RANGE	17.5		
Q3-Q1	8.5		
MODE	5		

# EXTREMES

LOWEST	HIGHEST
0	17.5
0	17.5
0	17.5
0	17.5

MISSING VALUE  
COUNT  
% COUNT/NOBS 0.15

# UNIVARIATE

VARIABLE=RTNKO

## MOMENTS

N	651	SUM WGTs	651
MEAN	136.802	SUM	89088.16
STD DEV	67.9056	VARIANCE	4611.17
SKEWNESS	1.28165	KURTOSIS	3.64333
USS	15188933	CSS	2997261
CV	49.6209	STD MEAN	2.66143
T:MEAN=0	51.4193	PROB> T	0.0001
SGN RANK	106.113	PROB> S	0.0001
NUM ~ = 0	651		

## QUANTILES(DEF=4)

100% MAX	557	99%	350
75% Q3	176	95%	253.6
50% MED	122	90%	211.8
25% Q1	92.8	10%	63.14
0% MIN	14.6	1%	24.66
RANGE	542.4		
Q3-Q1	82.2		
MODE	88		

## EXTREMES

LOWEST	HIGHEST
14.6	350
14.6	431
16.4	460
22.3	557

MISSING VALUE  
COUNT 1  
% COUNT/NOBS 0.15

# UNIVARIATE

VARIABLE=RTNKH

## MOMENTS

N	651	SUM WGTs	651
MEAN	11.1261	SUM	7243.1
STD DEV	11.8692	VARIANCE	140.88
SKEWNESS	1.72159	KURTOSIS	4.88096
USS	106.679	CSS	91571.7
CV	23.9172	STD MEAN	0.465193
T:MEAN=0	106.651	PROB> T	0.0001
SGN RANK	651	PROB> S	0.0001
NUM ~ = 0			

## QUANTILES(DEF=4)

100% MAX	76.9	99%	57.4
75% Q3	15.7	95%	34.6
50% MED	7.4	90%	28.46
25% Q1	2.4	10%	0.92
0% MIN	0.1	1%	0.1
RANGE	76.8		
Q3-Q1	13.3		
MODE	1		

## EXTREMES

LOWEST	HIGHEST
0.1	57.4
0.1	57.4
0.1	71.3
0.1	72.9
0.1	76.9

MISSING VALUE  
COUNT 1  
% COUNT/NOBS 0.15



## UNIVARIATE

VARIABLE=RTNKK

## MOMENTS

N	58	651	SUM WGTS	381	651
MEAN	58.87	60.2	SUM	330	2.29
STD DEV	22.18	20.2	VARIANCE	227	331.62
SKEWNESS	1.98	55	KURTOSIS	7.1	16.49
USS	48	410.1	CSS	259	51.3
CV	107	577	STD MEAN	0.2	76.46
MEAN=0	23	176	PROB> t	0.0001	
RANK	105	469			
NUM		649			

## QUANTILES(DEF=4)

100% MAX	50.1	99%	29.9
75% Q3	7.9	95%	18.4
50% MED	3.7	90%	14.6
25% Q1	1.4	10%	0.3
0% MIN	0	1%	0.1
RANGE	50.1		
Q3-Q1	6.5		
MODE	0.6		

## EXTREMES

LOWEST	HIGHEST
0	29.9
0	29.9
0.1	39.4
0.1	50.1

MISSING VALUE  
COUNT 1  
% COUNT/NOBS 0.15

## UNIVARIATE

VARIABLE=BTNKO

## MOMENTS

N	58	651	SUM WGTS	381	651
MEAN	58.60	60.2	SUM	330	2.29
STD DEV	59.18	20.2	VARIANCE	227	331.62
SKEWNESS	1.61	57	KURTOSIS	227	649.0
USS	45	166.2	CSS	2	314.5
CV	100	88.9	STD MEAN	0.0001	
MEAN=0	25	200	PROB> t	0.0001	
RANK	106	113			
NUM		651			

## QUANTILES(DEF=4)

100% MAX	278	99%	266.88
75% Q3	85.8	95%	198.18
50% MED	35.7	90%	143.9
25% Q1	15.1	10%	8.8
0% MIN	1	1%	2.2
RANGE	277		
Q3-Q1	70.3		
MODE	24.6		

## EXTREMES

LOWEST	HIGHEST
1.1	274
1.1	274
1.1	278
1.6	278

MISSING VALUE  
COUNT 1  
% COUNT/NOBS 0.15

## UNIVARIATE

VARIABLE=BTNKH

			MOMENTS		
	N	651	SUM	WGTS	651
	MEAN	4.50768	SUM		2934.55
	STD DEV	6.37402	VARIANCE		40.62832
	SKEWNESS	2.32123	KURTOSIS		10.82899
	USS	39.636.1	CSS		26408.3
	CV	141.404	STD MEAN		0.249818
	T: MEAN=0	18.0439	PROB> T		0.0001
	SGN RANK	103523	PROB> S		0.0001
	NUM == 0	643			

QUANTILES(DEF=4)			EXTREMES	
100% MAX	48.9	99%	34.336	
75% Q3	5.6	95%	18.46	LOWEST
50% MED	2.1	90%	11.78	0
25% Q1	0.8	10%	0.3	0
0% MIN	0	5%	0.	0
		1%		HIGHEST
RANGE	48.9			0
Q3-Q1	4.8			36.3
MODE	0.1			36.3
				39.5
				41.5
				48.9

MISSING VALUE		1
COUNT		
% COUNT/NOBS	0.15	

## UNIVARIATE

VARIABLE=BTNKK

			MOMENTS		
	N	651	SUM	WGTS	651
	MEAN	2.45333	SUM		1597.1
	STD DEV	3.73902	VARIANCE		13.9802
	SKEWNESS	3.27652	KURTOSIS		14.2356
	USS	13005.2	CSS		90871.6
	CV	152.407	STD MEAN		0.146544
	T: MEAN=0	16.7411	PROB> T		0.0001
	SGN RANK	98439	PROB> S		0.0001
	NUM == 0	627			

QUANTILES(DEF=4)			EXTREMES	
100% MAX	33.3	99%	18.272	
75% Q3	2.9	95%	10.2	LOWEST
50% MED	1.1	90%	0.1	0
25% Q1	0.4	10%	0.1	0
0% MIN	0	5%	0.1	0
		1%		HIGHEST
RANGE	33.3			0
Q3-Q1	2.5			20.9
MODE	0.1			21.8
				24.7
				26.7
				33.3

MISSING VALUE		1
COUNT		
% COUNT/NOBS	0.15	

# UNIVARIATE

VARIABLE=TOBLCW

## MOMENTS

N	651	SUM	651
MEAN	57.9101	SUM	37699.5
STD DEV	57.4594	VARIANCE	3301.58
SKEWNESS	2.6534	KURTOSIS	10.0014
USS	432908	CS	2146025
CV	99.2516	STD MEAN	2.25201
T: MEAN=0	25.7149	PROB>T	0.0001
SGN RANK	106113	PROB>S	0.0001
NUM	651		

## QUANTILES(DEF=4)

100% MAX	435.9	99%	263.648
75% O3	73.7	95%	169.74
50% MED	39	90%	119.72
25% O1	21.3	10%	12.72
0% MIN	4	5%	9.7
RANGE	431.9	1%	5.116
O3-O1	52.4		
MODE	18.7		

## EXTREMES

LOWEST	HIGHEST
4	275.1
4	295.7
4.1	422
4.6	433
4.6	435.9

MISSING VALUE  
COUNT 1  
% COUNT/NOBS 0.15

# UNIVARIATE

VARIABLE=LOBLCW

## MOMENTS

N	651	SUM	651
MEAN	3.76651	SUM	2452
STD DEV	4.25095	VARIANCE	18.0705
SKEWNESS	2.74596	KURTOSIS	10.0592
USS	209813	CS	11745.8
CV	112.862	STD MEAN	0.166808
T: MEAN=0	22.6071	PROB>T	0.0001
SGN RANK	105138	PROB>S	0.0001
NUM	648		

## QUANTILES(DEF=4)

100% MAX	30.3	99%	23.468
75% O3	2.4	95%	11.38
50% MED	1.1	90%	0.5
25% O1	0	10%	0.3
0% MIN	0	5%	0.1
RANGE	30.3	1%	
O3-O1	3.3		
MODE	1.1		

## EXTREMES

LOWEST	HIGHEST
0	25.7
0	26.3
0	28.6
0.1	28.8
0.1	30.3

MISSING VALUE  
COUNT 1  
% COUNT/NOBS 0.15

# UNIVARIATE

VARIABLE=INITRA

MOMENTS									
N	651	SUM	WGTS	2695	651				
MEAN	4.14077	SUM		2695	64				
STD DEV	3.72637	VARIANCE		13.8858					
SKEWNESS	2.25138	KURTOSIS		8.82613					
USS	20187.9	CSS		9025.79					
CV	89.9929	STD MEAN		0.146048					
T: MEAN=0	28.3521	PROB> T		0.0001					
SGN RANK	106113	PROB> S		0.0001					
NUM **= 0	651								
QUANTILES(DEF=4)									
100% MAX	31.65	99%	17.4344						
75% Q3	5.5	95%	11.318						
50% MED	3.05	90%	9.13						
25% Q1	1.57	10%	0.752						
0% MIN	0.17	5%	0.506						
		1%	0.2304						
RANGE	31.48								
Q3-Q1	3.95								
MODE	0.72								
EXTREMES									
LOWEST	0.17	HIGHEST	18.95						
	0.19		19.14						
	0.2		20.83						
	0.22		29.37						
	0.22		31.65						
MISSING VALUE									
COUNT	1								
% COUNT/NOBS	0.15								

# UNIVARIATE

VARIABLE=FINARA

MOMENTS				
N	651	SUM	WGTS	651
MEAN	4.43668	SUM		2888.28
STD DEV	4.44017	VARIANCE		19.7151
SKEWNESS	2.77366	KURTOSIS		13.8298
USS	25629.2	CSS		12814.8
CV	100.047	STD MEAN		0.174024
T: MEAN=0	25.4947	PROB> T		0.0001
SGN RANK	106113	PROB> S		0.0001
NUM **= 0	651			
QUANTILES(DEF=4)				
100% MAX	41.5	99%	20.624	
75% Q3	5.85	95%	13.054	
50% MED	3	90%	10.24	
25% Q1	1.55	10%	0.712	
0% MIN	0.17	5%	0.482	
		1%	0.21	
RANGE	41.33			
Q3-Q1	4.3			
MODE	1.47			
EXTREMES				
LOWEST	0.17	HIGHEST	21.1	
	0.19		27.04	
	0.19		27.05	
	0.19		37.91	
	0.2		41.5	
MISSING VALUE				
COUNT	1			
% COUNT/NOBS	0.15			

APPENDIX B

CHI-SQUARE TEST FOR DIFFERENCE

TANK LOSS FRACTION			
BLUE UNITS WITH MAIN BATTLE TANK	BLUE UNITS WITHOUT MAIN BATTLE TANK	RED UNITS WITH MAIN BATTLE TANK	RED UNITS WITHOUT MAIN BATTLE TANK
.376	.208	.166	.160
.149	.244	.111	.145
.325	.358	.144	.065
.233	.352	.179	.184
.374	.274	.132	.042
.298	.258	.203	.158
.168	.309	.160	.031
.289	.254	.141	.173
.134	.314	.217	.051
.236	.392	.183	.137
.324	.106	.058	.132
.318	.261	.025	.052
.392	.349	.092	.034
.372	.197	.194	.063
.155	.261	.105	.109
	.349	.217	.075
	.197	.141	.049
	.261	.152	.097
	.261	.126	.118
	.275		
	.423		
	.151		
	.169		
	.136		
	.186		
	.117		

The following equation was used:

$$\chi^2 = \sum \frac{(f_{ij} - e_{ij})^2}{e_{ij}}$$

f - Actual frequency  
e - Expected frequency

$$e_{ij} = \frac{R_i C_j}{T} \quad e_{ij} \geq 5$$

$R_i$  - Row total  
 $C_j$  - Column total  
 $T$  - Grand total

The level of significance-- $\alpha=.05$ .

TANK LOSS FRACTION OF BLUE UNITS	BLUE UNITS WITH MAIN BATTLE TANK	BLUE UNITS WITHOUT MAIN BATTLE TANK
0 - .25	5	9
.25 - $\infty$	10	4

FREQUENCY  
ROW SUM

14

24

COLUMN SUM

15

23

5.5	8.5
9.5	14.5

EXPECTED FREQUENCY

$H_0$ : There is no difference between the vulnerability of the blue units

$H_1$ : There is a difference

$$\chi^2 = .117$$

df=1

$$\chi^2 = 3.841$$

.95

df=1

Cannot reject  $H_0$

No significant difference

TANK LOSS FRACTION OF RED UNITS	BLUE UNITS WITH MAIN BATTLE TANK	BLUE UNITS WITHOUT MAIN BATTLE TANK
0 - .1	9	4
.1 - $\infty$	6	19

FREQUENCY  
ROW SUM  
13  
25

COLUMN SUM            15            23

5.13	7.87
9.87	15.13

EXPECTED FREQUENCY

$H_0$ : There is no difference between the lethality of the blue units

$H_1$ : There is a difference

$\chi^2 = 7.3$   
df=1

$\chi^2 = 3.841$   
.95

Reject  $H_0$  so there is a significant difference

TANK LOSS FRACTION OF RED UNITS	RED UNITS WITH MAIN BATTLE TANK	RED UNITS WITHOUT MAIN BATTLE TANK
0 - .13	6	12
.13 - $\infty$	13	7

FREQUENCY  
ROW SUM  
18  
20

COLUMN SUM            19            19

9	9
10	10

EXPECTED FREQUENCY

$H_0$ : There is no difference between the vulnerability of the red units

$H_1$ : There is a difference

$\chi^2 = 3.8$   
df=1

$\chi^2 = 3.841$   
.95

Cannot reject  $H_0$   
No significant difference

TANK LOSS FRACTION OF BLUE UNITS	RED UNITS WITH MAIN BATTLE TANK	RED UNITS WITHOUT MAIN BATTLE TANK
0 - .3	11	13
.3 - $\infty$	8	6

FREQUENCY  
ROW SUM  
24

14

COLUMN SUM

19

19

12	12
7	7

EXPECTED FREQUENCY

$H_0$ : There is no difference between the lethality of the blue units

$H_1$ : There is a difference

$$\chi^2 = .4527.3$$

df=1

$$\chi^2 = 3.841$$

.95

Cannot reject  $H_0$

No significant difference



## LIST OF REFERENCES

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